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MOLECULAR SPECTRA IN ASTRONOMY AND IN THE LABORATORY*

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Introduction. It is a painful but a proud honour to be called upon to give the Andrew McKellar Memorial Lecture. For Andrew McKellar was a man who gave us proof by his very life that the best in scientific originality and productivity can be combined with humility and humanity to produce a great man. He was not a man who dominated his immediate surroundings; he was not a man who stood out in the crowd. He was a man who in a quiet, direct and brilliant way went about his task and he will be remembered as a scientist and a friend long after more dominating but shallow men have passed from human memory.

This evening I would like to discuss in a very general way the part played by molecular spectra in astronomy. Particular attention will be paid to the question of what information about the molecule must be obtained before the observational data can be used. Two examples will be given of the type of laboratory work which must be carried out in order to obtain this information. Finally I would like to indicate some of the problems that the future might hold for astronomical applications of molecular spectra.

General Background. Atoms give spectra which consist of many quite widely spaced lines such that, more often than not, they appear to bear no relationship to each other. Molecules, on the other hand, give spectra which consist of groups of lines called bands. The lines within each band form regular series. A number of related bands can be grouped into a band system. If the molecular bands are photographed with a spectro-

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graph of low or medium dispersion, as often must be done in astronomy, the many lines of a band are not separated from each other and only a broad region of absorption (or emission) is observed. Figure 1a shows a part of one molecular band system photographed at low dispersion and figure 1b shows one band photographed at high dispersion.

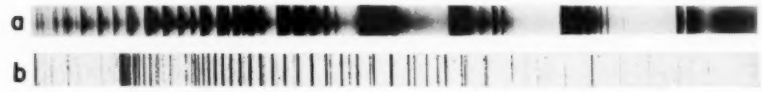

FIG. 1—Typical molecular spectra, (a) the emission bands of nitrogen photographed with a low dispersion spectrograph, (b) an emission band of the C_2 molecule photographed at high dispersion.

A band system contains many and perhaps many thousands of lines. Though the ability of these lines to absorb light (the line strength) varies widely from one band system to another and from one line to another in the same system, it is still possible to compare the line strengths of atomic and molecular lines in a useful way. In general, we can say that the strength of one atomic line is the same as the sum of the strengths of all the lines of a band system. Thus in going from atomic to molecular spectra we go from a relatively small number of strong lines to a very large number of weak lines. This is a rather general statement and it should be borne in mind that there are conditions under which it is not true.

The differences in line strengths and number of lines in atomic and molecular spectra have a profound effect on their appearance in astronomical spectra. Suppose that we look at the absorption spectrum of the atmosphere of a star. If we use a high dispersion spectrograph we will find it much more difficult to detect a small concentration of molecules than atoms since the strengths of the individual molecular lines is low compared to those of the atoms. On the other hand, if the atmosphere contains a large quantity of some suitable molecular species then each of the many molecular lines will give a substantial absorption at its own particular wave-length and the sum total of all these lines may result in an absorption which far exceeds that of an equal concentration of atoms. Thus molecules are difficult to observe in small numbers but once a large number exists, they greedily dominate the whole spectrum.

The regions in space where molecules can exist is limited by a number of factors. Molecules are dissociated into atoms by high temperature and by ultraviolet light. Thus in the atmospheres of high temperature stars molecules will not be found. Also molecules are not likely to play any

great part in gaseous nebulae illuminated by a bright central star, for here the low pressure and the intense ultraviolet light are both unfavourable to molecule formation. These facts severely restrict the role of molecular spectroscopy in astronomy. To illustrate this point, suppose that the universe were composed only of equal numbers of two types of stars, those with temperatures over 10,000° C. and those with temperatures under 2500° C. An observer on this earth would see many times more hot stars than cool because they are much brighter. Thus even if the number of cool stars in which molecules play an important role were equal to that of the hot stars in which only atomic spectra are found, an astronomer would find much more interesting material in atomic spectra.

Finally the role of molecular spectra is to some extent limited because the molecule is a more complex particle than the atom. This complexity causes the appearance of the spectrum and the number of molecules in a given region to be influenced by a number of factors which have little effect upon atomic spectra. Though there is no doubt that this very dependence of the intensity and the detailed characteristics of the spectrum upon many factors may make it a more delicate measuring device for conditions in the source, the problems of astronomy are usually so complex that an atomic spectrum, which is a simpler even if possibly a more crude measuring device, is to be preferred. Thus only when we are dealing with relatively simple problems or when the conditions within the source are already known within rather narrow limits is the molecular spectrum a useful tool.

Besides all the astronomical effects discussed above, which tend to limit the usefulness of molecular spectra, there also exists an astronomer effect. Most students of astrophysics learn a great deal about atomic spectra and very little about molecular spectra. When these students take up work in astronomy it is natural that, whenever circumstances allow, they concentrate on the observed atomic spectra. This in turn swells the publications on the atomic rather than the molecular side and we go the whole circle with new students finding very little need to understand molecular spectra in order to read the current publications. Though there is no doubt that atomic spectra must continue to play the dominant role in astrophysics, it is also probably true to say that, if all astronomers could be endowed with the knowledge of molecular spectra possessed by Andrew McKellar, there would be a great increase in the amount of information derived from the molecular parts of observed spectra.

After having considered above some of the reasons for molecular

spectra playing a somewhat minor role in astronomy, we will now consider where these spectra are of importance. At least four different types of spectra can be considered, these being spectra of cool stars, of comets, of interstellar molecules and of planets. The fact that the atmospheres of the planets are composed largely of molecular species is well known but, it is information well known only because absorption spectra of the molecules have been observed. Even within the atmosphere of the most familiar planet, the earth, we find that our knowledge of the rarer components such as ozone, nitrous oxide, methane and carbon monoxide has come almost entirely from the study of molecular spectra. Interstellar molecules which will be discussed further in a later section yield a few absorption lines which may have an importance far beyond their number or prominence. Comets give spectra which consist almost entirely of sunlight scattered by dust particles and molecular fluorescence bands. Certainly, however, the most varied sources of molecular spectra are the atmospheres of the cooler stars and, as is well known, these cooler stars are classified according to their molecular bands.

Now let us consider which molecules are likely to be observed in astronomical bodies. Certainly the range of conditions we encounter will vary greatly going from the high-pressure, low-temperature conditions of a planet such as Jupiter to the high-temperature, low-pressure conditions which might exist in certain stellar atmospheres. Nevertheless it is possible to define within rather narrow limits the types of spectra we are likely to encounter. Firstly we need only consider molecules containing not more than one rare element. A diatomic molecule such as PF is unlikely to be found since both phosphorus and fluorine are rare. Secondly, we can conclude that seldom are we going to find molecules containing more than three or four atoms. Larger molecules are difficult to synthetize and many of them are readily dissociated by heat and light. Also many of the larger molecules have relatively low vapour pressures and if they are produced in any of the cooler regions of space such as in the outer planets they are apt to condense into solids. There are however a few rather complex molecules such as ethane or ethylene which have a high stability and high vapour pressure and these may occur in planetary atmospheres. Thirdly, because in most regions of space there are numerous forces such as heat, ultraviolet light or highly excited atoms which tend to destroy molecules, only the more stable ones can be expected to survive in appreciable number. Finally a molecule can be observed spectroscopically only if it has spectra in a suitable wave-length range. Hydrogen is the most abundant element and molecular hydrogen must be abundant in many astronomical bodies. But the only known spectrum

of hydrogen in the range that is accessible to astronomers consists of a few extremely weak infrared lines. Thus, in spite of its large abundance, it is only in the outer planets that molecular hydrogen has been detected spectroscopically and even there the spectra are very faint. The CN molecule, on the other hand, has strong bands located near 4000 A. and is often observed in stellar atmospheres even though it must certainly be much less abundant than molecular hydrogen.

The question of what information can be derived from the observed molecular spectra of astronomical bodies will now be discussed. In order to obtain the maximum information from an observed spectrum it is necessary to make a mathematical model of the gas cloud under observation. If all the properties of all the atoms and molecules in the cloud are known then for a given temperature, pressure, abundance of the elements and other parameters the complete spectrum of the gas cloud can be predicted. Thus, by adjusting the many parameters until the predicted and observed spectrum agree, we can learn a great deal about the observed cloud. This calculation, which is the same in principle for atomic and molecular spectra, is very laborious and often impossible since we lack the necessary knowledge of the atomic and molecular properties. Fortunately it is often possible to obtain some very useful information by much simpler processes. Thus by observing the relative intensity of the lines in a band or by observing the relative intensities of bands in a band system, it is sometimes possible to determine the temperature of the source independent of all other parameters. Also if the absorption coefficient of the lines in a given band are known, we may be able to determine the amount of a given molecular species in the cloud independent of other parameters. Observed molecular spectra have also served as a basis for calculations on abundances of the elements, processes in interstellar space and in comets and on the relative abundances of the isotopes of the element. In this latter field only molecular and not atomic spectra can supply information and McKellar, who was the first to study the remarkable variation of the carbon isotope abundances in N-type stars, has discussed this question in his presidential address to this Society (McKellar 1960).

In the previous paragraphs the fact that it is necessary to have considerable information about a molecule before the observed spectra can be interpreted, has been emphasized. Just what information is required? The first and most essential datum is simply a knowledge of the spectrum emitted or absorbed by a molecule. Certainly, having observed a molecular band in the spectrum of some astronomical body, before we can proceed further we must know with certainty which molecule produced

the band. This problem is not always a simple one. Molecules found in astronomical bodies are often difficult to produce in the laboratory. CH^+, C_3 and NH_2, for example, occur in comets and in stellar atmospheres but only with considerable difficulty can they be produced in the laboratory and, even then, very seldom under controlled conditions. Thus the problem of identification of spectra by itself requires considerable laboratory work but this alone is insufficient for many purposes. The molecular constants most necessary for the study of astronomy are the positions of the low-flying electronic states, the distances between the atoms in the molecules, the frequencies with which the nuclei vibrate against each other, the energy necessary to dissociate the molecule into atoms and the f-value or transition probability between states. All of these constants can, in principle, be determined from a study of the spectrum of the molecule in the laboratory but there are many difficulties in actually carrying out this work and only for very few molecules are all these constants known. There is no doubt, however, that before full use can be made of the spectra observed in astronomy, accurate values for these constants will have to be determined.

Laboratory Studies. As examples of the type of work necessary in order to interpret astronomical molecular spectra, the history of laboratory research on CH^+ and SiC_2 will be presented. These studies are not more significant than many others but are examples with which I am familiar.

When the spectra of certain distant stars are photographed at high dispersion, absorption lines which arise from atoms and molecules in interstellar space are observed. The strongest lines which are due to Na, Ca^+, K, Ti^+ and Fe were soon identified. The fact that certain lines are probably due to molecules was first suggested by Swings (1937) and by Swings and Rosenfeld (1937) and then proved beyond all doubt by McKellar (1940). These authors showed that under the low temperature conditions existing in interstellar space, molecular bands were reduced to one or two lines. McKellar was able to assign three lines to CN and four to CH. There remained however four sharp lines at 3579, 3745, 3957 and 4232 A. which could not be identified. McKellar (1941) assumed that these four lines are due to one unknown molecule and showed that the molecule is probably a diatomic hydride.

In the spring of 1941 G. Herzberg attended a conference at Yerkes Observatory where these interstellar lines were discussed and he reached much the same conclusion as McKellar. He went one step further, however, and concluded that the spectrum was that of the CH^+ molecule. Since no spectrum of this molecule had as yet been found he set out to find it.

The laboratory work was quite simple. A trace of benzene was added to helium and an electric discharge passed through this mixture of gases. The light from this discharge was photographed at high dispersion on a grating spectrograph. With very little effort a new band system was found, which upon close investigation, proved to be the spectrum of CH^+. Furthermore it was shown beyond any doubt that these bands could account for three of the four unidentified lines. Thus Herzberg's predictions were confirmed (Douglas and Herzberg 1942).

The fourth unidentified line at 3579 A. was more troublesome to identify. This region of the laboratory spectrum was overlapped by bands of other molecules and there was little chance of finding the 3579 A. line even if it did occur. From an extrapolation of the observed lines a rough prediction of the position of the fourth line could be made and it came close to 3579 A. but not really in very good agreement. Therefore Douglas and Herzberg concluded that it was probable that the 3579 A. line did not arise from CH^+.

The problem rested in this unsatisfactory state for eighteen years. In 1959, Morton set out to find the spectrum of C_2^+ using a discharge tube not very greatly different from that used by Douglas and Herzberg. He did not succeed in finding the spectrum of C_2^+ but did find that he had developed a very good source for the CH^+ spectrum. With this source he was able to find a band from which the position of the fourth CH^+ interstellar line could be calculated exactly. This new band showed that the line lay at exactly the position of the observed interstellar line and that the fourth line was beyond any doubt due to CH^+ (Douglas and Morton 1959). At the present time all the observed sharp interstellar lines have been identified.

The Merrill-Sandford Bands. The spectrum of the C_2 molecule is well known and is found in spectra of many comets and cool stars. The Si_2 molecule is also known in the laboratory but it has not been observed in any astronomical source. It seems probable that the heteronuclear molecule SiC should exist and be observed both in the laboratory and in astronomical bodies. Up till now, however, no spectra of the SiC molecule have been observed.

About six years ago B. Kleman set out to find the spectrum of SiC. Since the spectrum of the C_2 molecule can be observed in a carbon furnace, he quite reasonably assumed that if he added a small amount of silicon to the furnace then SiC would be formed and perhaps could be observed.

Kleman used a carbon tube furnace which was capable of giving temperatures up to 3000° C. He found that with silicon in the furnace at

a temperature of about 2300° C., the gas in the centre of the carbon tube emitted a strong spectrum in the visible region. A photograph of the spectrum on a high resolution spectrograph showed it to be very complex and not at all like the spectrum expected for the SiC molecule. At this stage it was recalled that some years earlier Merrill (1926) and Sandford (1926, 1950) had observed strong unidentified bands in the spectra of certain cool stars such as RY Draconis. When the spectrum observed in the laboratory was compared with that published by Sandford, there was no doubt that the bands were identical. A part of the spectrum excited by Kleman together with that obtained by Sandford are shown in figure 2 (Kleman 1956).

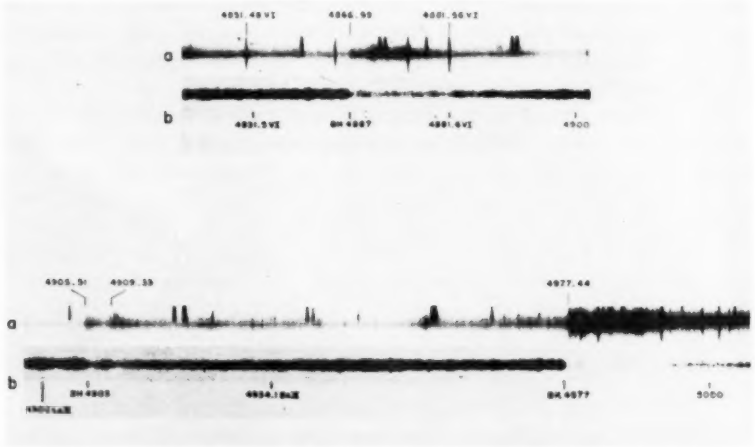

FIG. 2—A comparison between the Merrill-Sandford bands in VX Andromedae (b), and the emission bands from a carbon furnace containing silicon (a).

Though there was no doubt that Kleman had reproduced the unidentified stellar spectrum, there still remained the problem of identifying the molecule that emitted the spectrum. By a series of experiments it was established that only silicon and carbon were necessary for its appearance. Also, in spite of the complexity of the spectrum, a partial vibrational analysis was possible and this analysis indicated that the molecule contained one heavy atom linked to two bonded lighter ones. From this work, it was concluded that the molecule emitting the spectrum most probably was SiC_2. Kleman was unable to carry the analysis of the bands beyond this point and up till now no detailed analysis of the

spectrum has been obtained. We are still awaiting the discovery of a low temperature source from which the SiC_2 emission band can be obtained and analysed and it is also of interest to note that we are still awaiting the discovery of a source of the SiC bands which Kleman and all subsequent investigators have failed to find.

Future Work in Molecular Spectroscopy. Here we will consider, very briefly, certain aspects of future research in molecular spectra in astronomy and the related laboratory work. There seems not much doubt that in the near future, research in the laboratories and in the observatories will continue along much the same lines as in the past. This in no way makes it a limited field. More sensitive light detectors which are now being tested will probably increase greatly the number of high resolution spectra available for study. Satellite astronomy will allow investigations far into the ultraviolet and infrared where atmospheric absorption prevents observation from the earth's surface. And there is, of course, the continuing flow of new information coming from the conventional instruments of the many observatories of the world. Finally, the discovery of one or more molecular lines by radio astronomy is a definite possibility.

Much new laboratory research will be required to keep up with the demands of astronomy. We need to know not only the wave-lengths of the bands emitted or absorbed by a molecule but a great deal more detail about the behaviour of the molecule. At the present time even considering diatomic molecules composed of only the most abundant elements, we find that many of the molecular constants are unknown. Some of these molecules, such as C_2^+ or SiC mentioned above, are totally unknown. For most others, we have some spectra which have been analysed but we lack much information. For only a half-dozen or less molecules, are the data sufficient to satisfy even the present needs of astronomy.

If we turn to triatomic molecules then we find even less is known. For example, a list of the triatomic molecules that can be formed from the three relatively abundant elements, carbon, nitrogen and oxygen, is given in Table I. Of these twenty-four different molecules, the four that are underlined are well known stable chemical compounds. Spectra of two others, C_3 and NCO, are known and two band systems of NCO have been analysed in considerable detail. Spectra have been found which are attributed to N_3 and NCN but here the interpretation is very uncertain. Nothing is known of the other sixteen and yet on theoretical grounds it is possible to predict that many of them will have spectra of interest. If other abundant elements such as hydrogen and silicon are also considered then the number of possible triatomic molecules becomes very large indeed and the fraction of these known to spectroscopy is

TABLE I

TRIATOMIC MOLECULES WHICH CAN BE FORMED FROM OXYGEN, NITROGEN AND CARBON

O O O	O N N	C N O
C C C	N C C	C O N
N N N	C N C	C C O
N C N	N O O	C O C
C N N	O N O	C O O
N O N	N C O	O C O

insignificant. Since experience has shown that triatomic molecules do play a role in the atmospheres of stars, comets and planets, laboratory studies of many more of this great number of molecules are necessary if we are to proceed with confidence in the analysis of observed astronomical spectra.

Probably the most important advance in astronomy in recent years has been the introduction of radio astronomy. A considerable measure of the success of this technique has come from the discovery of one spectral line in the radio frequency region, that of the hydrogen atom. The question of whether or not other lines may be found has been discussed quite fully by Shklovsky (1960). It appears that only the OH line near 1668 Mc./sec. and the CH line near 3180 Mc./sec. are likely to be found. The position of the OH line has been determined quite accurately from the laboratory microwave measurements. Attempts have been made to find this line but so far without success. The frequency of the CH line has been determined only from optical measurements of the CH spectrum and the accuracy of these measurements is low. It appears that it will be very difficult to obtain laboratory microwave measurements of the frequency. Thus at present the search for the CH line is hampered by the lack of knowledge of the frequency at which a search must be conducted. There is no doubt that a much better value for the frequency of this line could be found by a very precise measurement of the CH bands near 4000 A. and this work should be done in the near future. At present it is impossible to predict whether or not the methods of radio astronomy will ever detect the CH line but it is certain that the detection of this line would be a major step forward in our understanding of interstellar matter.

In the previous section it has been stressed that we require a great deal more information about many molecules. I fear that this information

will be forthcoming only very slowly. At one time the study of simple molecules was a suitable field of study for a young physicist. This is no longer so. Spectroscopy is old-fashioned physics and it is largely in the chemistry departments of universities that we find spectroscopy today. Chemists, for the most part, are interested in more complex molecules which are of no interest to astronomy. Now we are faced with the fact that we require a large amount of information which can be obtained only by a major effort on the part of some large group and there is no such group interested in making the effort. Perhaps now astronomers themselves must take up laboratory research in spectroscopy. Few observatories now have spectroscopy laboratories. But perhaps this will have to change and in the future we will see astronomers meeting problems in their observations and carrying these problems into their own laboratories. If such a development occurs, we will certainly miss more than ever a man of the talents of Andrew McKellar who was completely at home in both the observatory and the laboratory.

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THE REMOVAL OF A CHROMIUM BASE LAYER FROM AN OPTICAL MIRROR

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When the 74-inch telescope of the David Dunlap Observatory was being assembled in 1934 the secondary mirrors, both Newtonian and Cassegrain, were given aluminium coatings at the California Institute of Technology by the then newly-developed vacuum technique. At that time it was considered good practice to use a base coat of chromium, the belief being that the aluminium adhered better to chromium than to glass and so formed a more durable film. The Cassegrain was given a chromium base coat, but for some reason the Newtonian was not.

Chromium is not easily attacked either by caustic or by acids, and so subsequent coatings of aluminium were put on over the chromium, as it was intended should be done. However, in the course of time, a patchiness of the base coat developed, and there was growing indication that even new coatings of aluminium did not have as good reflecting qualities as formerly, especially in blue light. This was confirmed by comparing the reflectance of the Newtonian and the Cassegrain. The problem then was to remove the chromium base coat.

In his book "Vacuum Deposition of Thin Films" (John Wiley and Sons, 1958) Holland refers (on page 342) to the difficulty of removing chromium base coats, and describes a method in which the mirror is immersed in hydrochloric acid, and finely divided zinc powder is dusted over the mirror surface. He warns that the method is drastic and the reaction violent; and we were hesitant to risk the mirror to the treatment.

With the advice and help of Dr. M. W. Lister of the Department of Chemistry of the University of Toronto, we experimented with some pieces of glass coated with chromium. At his suggestion the samples were smeared evenly with a mixture of soap and water and zinc powder and then wetted with a one-third solution of hydrochloric acid in water. With this technique the reaction could be localized and slowed up if necessary by adding water. The method worked very well indeed. The reaction was not violent, and the chromium came off with surprising ease. There remained on the mirror a few dark smears which resisted repetition of the treatment; they were reduced, but not altogether removed, by successive treatments of nitric acid, soap and light buffing.

When the cleaned mirror was re-aluminized and installed on the telescope there was a marked improvement in efficiency—about one magnitude in the region of 4000 A.

WILHELM HEINRICH WALTER BAADE, 1893–1960*

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Walter Baade died on June 25, 1960. Everyone working in astronomy knew some side of Walter Baade. Some knew him from his terse, important scientific papers which distilled the results of numerous painstaking observations. Many knew him from scientific meetings where he was at his most brilliant in informal discussion and personal give-and-take. Most remember his animated conversations delivered while walking with people, interspersed with long halts while he rested his leg and used the opportunity to spiritedly drive home some point. It was following an operation on this same bad hip, that he died of respiratory failure at the age of 67.

At times his passionate interest in astronomy was reflected in the intense partisanship of his arguments, the explosive energy of his interruptions, the tenacity of his pursuit of a point. But it was his most important characteristic that he always tried to substantiate his ideas by proof of observation. His own cache of accurate personal observations often served his purposes. If need be, however, he could back his arguments with references to the observations of others, with which he was always well acquainted. He knew from correspondence, conversation and reading the journals, both the published and unpublished material from every other observatory in the world.

It would be of great interest to know exactly when and why he developed the two characteristics which are so outstanding in him: his zeal for astronomy and his insistence on the observational method. Some clues are certainly present in a broad sense from his early life and training.

He was born in Schöttinghausen, Germany, in 1893 and studied at Göttingen from 1913 to 1919 where he received a classically thorough German education. Among other accomplishments, he was early able to read Greek and Hebrew. Between 1919 and 1925 he served as scientific assistant to the famous mathematician, Felix Klein. Wolfgang Pauli was sent to Göttingen in 1921 by his teacher, Sommerfeld, in Munich. Baade met the young physicist and the two became lifelong friends.

From 1927 to 1931 Baade served as an Observator at the Hamburg Observatory in Bergedorf. There he began systematic observations of comets, minor planets, star clusters, variable stars and galaxies with the relatively small instruments of the observatory. His publications of these data gained him a Rockefeller Scholarship to visit the Mount

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Wilson Observatory in 1929. He moved to this country to take up a permanent staff position in 1931. Almost immediately he began to amass a matchless collection of fine astronomical photographs with the large telescopes.

Some knew Baade in this capacity as the observer, as the perfectionist, the astronomer who went at first to Mount Wilson and later to Mount Palomar for long runs with the big reflecting telescopes. There he would completely concentrate on obtaining the finest photographic plates by continually working to obtain the last degree of accuracy of focus, the best developing techniques, by striving for absolutely error-free guiding. Baade took a fierce pride in his astronomical photographs and made no secret of the fact that he considered his plates to be the best. Most people were inclined to concede the nomination.

As my thesis advisor I knew Baade in a different way than most astronomers. As might be expected, in this capacity his outstanding characteristic was his ability to stimulate students, firing them with the desire to observe, and discover, and resolve controversies with facts. He also, however, gave the genuine warmth of friendship. No matter how forcibly he might argue a scientific point, one had no doubt that he remained a firm and true friend. I think it was this knowledge which he gave people, that he would argue questions purely on their scientific merits, which was one of the reasons that enabled the frank and forceful discussions of astronomical problems which always sprang up around him wherever he went.

Baade had taken out first papers to become an American citizen before the Second World War. When the papers were lost in a move from one house to another it was typical of Baade that he spurned any further contact with bureaucracy. As a consequence when the Second World War occurred, he was declared an enemy alien and restricted to the Pasadena-Mount Wilson vicinity. Since many astronomers became engaged in war work at that time, Baade had considerable amounts of time with the 100-inch telescope at his disposal. Further, the Los Angeles lights were dimmed as a war measure and Baade had an unusually dark sky with which to work.

These events led directly to the peak achievement of his career, the resolution of the stars in the nucleus of the Andromeda Galaxy and in its two companions, M 32 and NGC 205. He had just previously obtained a very fine blue-sensitive photograph on which he suspected incipient resolution. Reasoning that the background which he was trying to resolve was dominantly of red colour index, he switched to red-sensitive plates and, after long accurately-guided exposures on nights of perfect

seeing, he achieved the nearly impossible and resolved individual background stars in these local group galaxies.

In 1944, at the same time that he published the observational results, Baade interpreted these results in terms of galaxies which contained the populations I and II. This population idea was his most famous contribution and proved so useful a concept and so captured the imagination of astronomers that an entire meeting, the Rome Conference of 1957 which Baade attended, was held on this subject. Baade always roughly thought of his population II stars as "old" stars and his population I stars as "young" stars. He believed that we did know and could know a great deal about how stars and galaxies were formed. In fact several times this led him to make the curious statement that the study of "cosmology", or the nature of the universe in the large, was hopeless but that "cosmogony" or the *origin* of the universe was quite accessible to solution.

In the years following this Baade did not publish very much. He apparently felt emboldened to systematically collect plates on galaxies, globular clusters, supernovae and many other projects. He seemed to want to wait until he had the absolutely definitive observations on each problem before he reduced and published the results. At this time he had very great influence with many astronomers throughout the world and he urged them on to important problems and to undertake crucial investigations. As an example, he was always extremely aware of the importance of colour-magnitude diagrams of groups of stars and therefore very aware of the need for precise photometric standards. Although he had already committed a great deal of his life to the arduous task of photographically transferring magnitude scales into various desired regions, he welcomed the more accurate photoelectric techniques and encouraged Stebbins and Whitford in their initial photoelectric measures of standards in Selected Areas.

In 1953 Baade obtained a new modulus to the Andromeda Galaxy. He had failed to discover RR Lyrae stars in M 31 with the newly-finished 200-inch telescope. This result, together with increasing knowledge of the absolute magnitude of the globular cluster giants which he had resolved in 1944, led him to announce a distance modulus of $m\text{-}M = 23.9$ mag. This replaced the $m\text{-}M = 22.4$ mag. which had been used almost since Hubble's proof in 1924 that M 31 was an extragalactic system. A number of startling consequences were immediate: (1) The increased distance to Andromeda required a shift of 1.5 mag. in the zero point of the classical Cepheid period-luminosity relation. (2) The type II (globular cluster) Cepheids had a Cepheid zero point about 1.5 mags. fainter than the classical Cepheids. (3) That insofar as distances to extragalactic

nebulae rested on classical Cepheid calibration, that distances to remote objects in the universe had to be roughly doubled. (Sandage eventually derived a Hubble constant of a factor 8 less.)

After retiring in 1958, Baade gave an extremely stimulating lecture course at Harvard. He then went on to the Mount Stromlo Observatory in Canberra, Australia. He spent six months there, observing among other things the RR Lyrae stars in the centre of our own galaxy (about which there had been controversy in the preceding years), and had stimulating and pleasant associations with the staff there.

Finally, in 1959, at the age of 66, Baade and his wife "Muschi" returned to their native Germany. Baade himself became Gauss professor at Göttingen, where he had started his student days. While he was in the process of reducing and readying his rich store of observational material for publication. he underwent the hip operation which led to his death in 1960.

His remaining material and papers are now being processed both at the Leiden Observatory and Mount Wilson and Palomar Observatories.

SIR HAROLD SPENCER JONES, 1890–1960*

By W. M. Smart
Royal Society of Edinburgh, Scotland

The sudden death, on November 3, 1960, of Sir Harold Spencer Jones at the age of 70 has deprived science of an outstanding figure and an acknowledged leader of British and international astronomy.

Spencer Jones was born in London on March 29, 1890. He was educated at Latymer Upper School, Hammersmith, and Jesus College, Cambridge, where he had a specially distinguished undergraduate career, followed by an Isaac Newton Studentship, the award of a Smith's Prize and election, in 1914, to a Fellowship of his college; he became an Honorary Fellow in 1933. Meanwhile, in 1913, he had been appointed Chief Assistant at the Royal Observatory, Greenwich; but his astronomical career was soon to be interrupted when, during the First World War, his scientific abilities—particularly in optics—were put at the disposal of the Ministry of Munitions. In 1923 he was appointed H.M. Astronomer at the Cape of Good Hope Observatory, and ten years later he returned to Greenwich as Astronomer Royal, succeeding Sir Frank Dyson who had previously been Astronomer Royal for Scotland.

His first research after the War was on the proper motions of the brighter stars within 17° of the north pole in relation to spectral type. This was followed by a pioneer investigation on the absorption of light in interstellar space, attributed to selected scattering.

An impressive series of observations with the Cookson floating telescope, used for the determination of latitude variation arising from minute fluctuations in the position of the earth's rotational axis, were analysed by Spencer Jones with such success that the appropriate values of the latitude were used in the reduction of the relevant observations of planets and stars.

On his arrival at the Cape, Spencer Jones found several long series of observations still awaiting treatment and soon he was embarked on the most prolific period of his career. He first dealt with observations of occultations of stars by the moon, made between 1880 and 1922; these enabled him to compare the positions of the moon with those calculated from E. W. Brown's recently published tables and to deduce corrections to the principal adopted lunar constants. He next tackled the long series

*The Obituary Notice of Sir Harold Spencer Jones has been written for joint publication in the *Year Book of the Royal Society of Edinburgh* and in the *Journal of the Royal Astronomical Society of Canada*.

of observations of the sun, Mercury, Venus and Mars made at the Cape between 1836 and 1924. Here he detected residual fluctuations in the longitudes of the four bodies which showed parallel characteristics; these fluctuations he attributed to irregularities in the rate of rotation of the earth—a subject which engrossed his attention for over three decades.

Observations of Mars at the favourable opposition of 1924 provided an introduction to the difficult problem of determining the solar parallax and, although the final result was not of high weight, the investigation must have afforded Spencer Jones a deep insight into the subtleties to be encountered in his later and famous determination of the solar parallax from observations of Eros during the opposition of 1930–31. No fewer than twenty-four observations took part, with Spencer Jones in charge of the preliminary arrangements and of the subsequent calculations. The final result, announced in 1940, of $8.790'' \pm 0.001''$—corresponding to the average distance of the earth from the sun of 93,005,000 miles—is not likely to be supplanted, if at all, for many decades to come. One subsidiary result of importance was the ratio of the earth's mass to that of the moon, namely 81.27:1. A kindred work was his determination of the aberration constant derived from the line-of-light velocities of nineteen stars; if the velocity of light is assumed known, the solar parallax is at once deduced.

Shortly after his arrival at the Cape, Spencer Jones began a systematic programme of measuring stellar distances at a time when several observatories had been lured away from this fundamental work by the more exciting developments in spectroscopy. When he left for Greenwich, about 500 parallaxes had been published—and the work is still going on, to the great advantage of astronomy in general. When he returned to Greenwich he was still chiefly immersed in the Eros observations already alluded to. A further discussion of the Cookson observations from 1911 to 1936 brought to light the lunar tide effects on the variation of latitude.

Even before the end of the Second World War the removal of the Observatory from Greenwich became inevitable owing to the increasing pollution of the atmosphere and to modern street-lighting. In due course, but after many delays and frustrations, the instruments and staff were transferred to Herstmonceux Castle in Sussex.

After his retirement in 1955 Spencer Jones occupied with acceptance the important post of Secretary General of the International Council of Scientific Unions.

Spencer Jones received many honours: a knighthood in 1943, K.B.E. in 1955, a Royal medal of the Royal Society (he had been elected a

Fellow in 1930), the Bruce medal of the Astronomical Society of the Pacific, the Lorimer medal of the Edinburgh Astronomical Society, honorary degrees of D.Sc. of Paris, Brussels, Delhi, Durham, Calcutta, Oxford, D.Phil. of Copenhagen and LL.D. of Glasgow. He was an honorary member of numerous astronomical and scientific societies and a Foreign Associate of many academies and institutes. He became an Honorary Member of the Royal Astronomical Society of Canada in 1947, and an Honorary Fellow of the Royal Society of Edinburgh in 1951. He occupied in turn every post—from Secretary to President (1937–39)—of the Royal Astronomical Society. He was President of the International Astronomical Union in the difficult post-war years 1945–48, and the first President of the Institute of Navigation on its foundation in 1947.

His books included "General Astronomy", "Worlds without End", and "Life on other Worlds".

Spencer Jones was a man of great charm and dignity, a loyal friend, a great administrator, and one ever ready to help his colleagues and young astronomers.

He married, in 1918, Gladys Mary Owers who, with two sons, survives him.

CANADIAN SCIENTISTS REPORT—XXVI

STELLAR ECLIPSES AND STELLAR INTERIORS

By Alan H. Batten
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It may seem surprising, at first sight, that there is any hope of learning about the deep interiors of stars by watching their eclipses of each other. The eclipses referred to, of course, are those which occur in double star systems whose position in space is such that an observer on earth may see the two component stars regularly eclipse each other. How can such a chance and superficial phenomenon reveal the physical conditions deep inside these stars? The answer to this question may ultimately be derived from Newton's Law of Gravitation, for the stars in eclipsing systems, like those in all binary systems, are revolving around a common centre of mass in orbits determined by this law. It is this fact that opens the way to the investigation of the physical structure of the stars.

As early as 1899, H. N. Russell showed how an upper limit to the mean density of the two stars of an eclipsing system may be deduced from observations of the variations of its light. It is of interest to note, here, that an amateur astronomer, Alexander Roberts, arrived at the same result independently, and almost simultaneously. An outline of their argument follows. Unless both stars are identical, the eclipses will be alternately deep and shallow, as first the hotter and then the cooler star is eclipsed. The orbital period of the system is the interval between two successive eclipses of the same sort, and it may be determined from a sufficiently large number of observations. When the period is known, the variation of the light of the system may be plotted to give a *light curve*, such as the one shown in figure 1. Any system governed by Newton's Law of Gravitation must also obey Kepler's three laws, for these may all be deduced from Newton's Law. For the solar system, Kepler's Third Law states that the mean distance, a, of any planet from the sun, and its orbital period P, satisfy the relation

$$\frac{a^3}{P^2} = \text{constant}.$$

Strictly speaking, this quantity is not exactly the same for all planets, it is proportional to the sum of the masses of the planet and the sun.

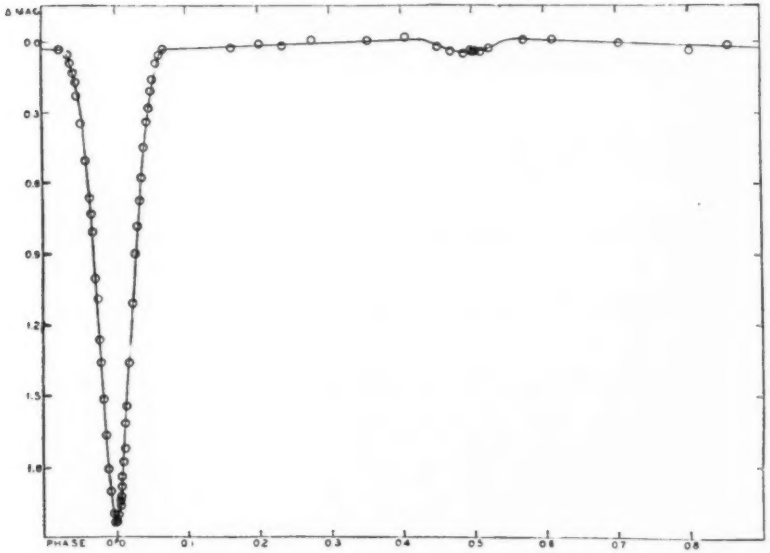


FIG. 1—A photoelectric light curve for the system TX Ursae Majoris obtained between 1935 and 1942 by C. M. Huffer. The eclipses are partial, and one is much deeper than the other, indicating a great disparity in the surface brightnesses of the two stars. The small variation of light between eclipses is due to "reflection" of the light of the brighter component by the fainter. The secondary eclipse is almost exactly half a period after the primary, suggesting a nearly circular orbit (see text). The magnitudes are on an arbitrary scale, the phase is expressed as a fraction of the period. (*Ap. J.*, vol. 105, p. 217, 1947.)

The sun is so much more massive than the planets that a^3/P^2 is virtually constant. In a double star system a must denote the mean separation of the two stars. If a is expressed in astronomical units, and P in years, and if the masses of the two stars are M_1 and M_2 times the mass of the sun, Kepler's Third Law becomes

$$\frac{a^3}{P^2} = M_1 + M_2.$$

After some analysis, the light curve will provide the ratios of the radii of each of the two stars to their mean separation. These quantities may be denoted by R_1/a and R_2/a. The mean density of each star is its total mass—the total quantity of matter in it—divided by its total volume. The latter is well known, and is $\frac{4}{3}\pi R_{1,2}^3$. Similarly, the mean density

of the system is its total mass divided by its total volume, and is, therefore,

$$\frac{M_1 + M_2}{\frac{4}{3}\pi\left(R_1^3 + R_2^3\right)}$$

$$= \frac{a^3/P^2}{\frac{4}{3}\pi\left(R_1^3 + R_2^3\right)}$$

$$= \frac{3}{4\pi P^2\left(\frac{R_1^3}{a^3} + \frac{R_2^3}{a^3}\right)},$$

which can be evaluated from the data provided by the light curve. If P is expressed in years, the mean density of the system will be given in units of the solar mean density. Usually P is given in days and an extra numerical factor must be introduced into the formula. Russell's demonstration differed a little from this, as at that time no way was known to derive R_1/a and R_2/a exactly. The methods had yet to be developed—by Russell. To determine the mean densities of the individual stars, each of M_1, M_2, R_1, R_2 must be known. These cannot be found from the light curve alone.

When Russell first evaluated these mean densities, he found that they were often less than that of the sun (the mean density of which is about one and a half times the density of water). Both the sun and the stars, of course, must have central densities much higher than their mean densities. The matter near the centre of a star is subjected to the pressure exerted by the whole mass of the star. If it is to resist this pressure, so that the star will not collapse, this matter must be very closely packed—that is, very dense. It is of interest to consider what may be the ratio of central to mean density. A rough estimate can be made if the mass and radius of a star are known, for then the approximate central pressure may be computed. (For the sun it is about thirteen thousand million atmospheres.) The density of a gas, however, depends on the temperature, as well as the pressure. To evaluate it precisely, therefore, a theoretical model of the star must be constructed, for which the pressure, density and temperature of the matter may be computed for any point inside the star. Such models have indeed been made, and they lead to definite predictions about the ratio of central to mean densities inside the stars. The predictions of scientific hypotheses must

be verifiable to be useful, and it is perhaps surprising that the study of stellar eclipses can provide verification.

Newton first showed, in the *Principia*, that a truly spherical body always acts, gravitationally, as if its entire mass were concentrated at its centre. It is said, therefore, to act as a *mass-point*. The components of many eclipsing systems, however, are close enough to each other to distort each other, and so they are no longer spherical. As a consequence, they no longer attract each other as if they were mass-points—unless, of course, they really are highly concentrated toward their centres. It is tacitly assumed, however, in the mathematical theory of elliptical orbits obeying Kepler's laws, that the two stars are mass-points. Two real, distorted stars, therefore, cannot be expected to obey Kepler's laws exactly. The stars will be perturbed in their motions, just as the earth is perturbed, in its motion about the sun, by the other planets in the solar system. Their orbits will no longer be truly elliptical. The less concentrated are the individual stars, the greater will be the perturbations. From observations of these perturbations, therefore, the degree of concentration of the matter in the components of a binary may be estimated. This concentration is usually defined by the ratio of the central density to the mean density. Exactly similar principles are used to estimate the shape of the earth, and the distribution of matter inside it, from observations of the perturbations of the orbits of artificial satellites. The departures of the orbit of a binary component from true elliptical motion are very small, and over a small number of revolutions, the orbit remains very nearly an ellipse. Slowly, however, the ellipse is modified and, after some years, although the orbit is still indistinguishable from an ellipse, the longest axis of that ellipse has changed its direction. The line of the longest axis is called the *line of apsides*, and the change is known as *apsidal rotation*. The rate of apsidal rotation depends on the degree of central concentration of the two stars, and on their sizes, relative to their separations. The latter, as has been explained, may be found from the light curve of an eclipsing binary. If, then, the rate of apsidal rotation can be determined, the mean concentration of the stars may be deduced. Once again, the first man to do this was Russell, but today, more accurate equations derived by Sterne, in 1939, are usually used.

The direction of the line of apsides may be defined by the angle it makes with the line of sight, but convention uses this angle less 90°—the so-called *longitude of periastron*, ω. When two stars move in elliptical orbits, the secondary (shallower) eclipses no longer necessarily occur half-way between the primary eclipses—as they must in circular orbits—

but they are displaced by an amount proportional to the cosine of ω. If, then, ω is changing—it should increase steadily—the secondary eclipses will move slowly back and forth, relatively to the primary eclipses. In fact, both eclipses will occur sometimes earlier, sometimes later, than the times which would be predicted from a truly elliptical orbit in which Kepler's laws are obeyed. This is because the stars eclipse each other, in successive revolutions, at slightly different points on the circumferences of their orbits; while in truly elliptical orbits, the eclipses always occur at the same points in the orbits. A glance at figure 2 will

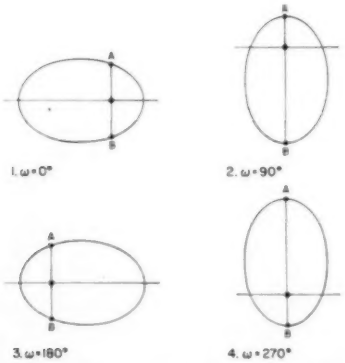


FIG. 2—Four possible positions of an elliptical orbit. The diagrams show the relative orbits of a hot star about its cooler companion. The deeper (primary) eclipse always takes place at A. The observer is looking along the direction BA. The angle ω is measured counter-clockwise from the line perpendicular to AB.

show how the relative positions of the two eclipses may change. It shows four orientations of the relative orbit of a hot star around a cooler one. The orbit is drawn with a large eccentricity to make the point clearer, but the principle is the same for all eccentricities. In all four positions the primary eclipse occurs when the star is at the point A, and the secondary eclipse when it is at B. In the first, $\omega = 0°$: Kepler's Second Law implies that the journey from A to B must take much longer than that from B to A. (The star is revolving counter-clockwise.) The secondary eclipse is as late as it can be: how late this is depends on the eccentricity, e. In the second, $\omega = 90°$ and the line AB lies along the major axis of the ellipse and divides the area of the ellipse into two equal parts. By Kepler's Second Law, therefore, the secondary eclipse occurs exactly half-way between two successive primary eclipses. The third position, $\omega = 180°$, is a reversal of the first. The secondary eclipse is as early as it can be.

Finally, $\omega = 270°$, is a reversal of the second position: the secondary eclipse is again midway between successive primary eclipses. If, then, many eclipses are observed and timed, over a long period, the rate of apsidal rotation may be deduced. This leads to the very beautiful result that from observations of the light changes of an eclipsing system, without knowledge of the masses or absolute sizes of the component stars, the distribution of matter inside those stars may be determined.

So far, it has been assumed that the only cause of apsidal motion is the distribution of matter inside the star. The analogy that was drawn between this effect and the planetary perturbations in the solar system is, however, closer than it might at first appear. Indeed, if a binary system should be accompanied by a third star, at some distance from it, this star will perturb the orbit of the close pair, and induce rotation of its line of apsides. Such systems are not uncommon, so that if reliable information about the interiors of the stars is to be obtained from apsidal rotation, it is important to know whether or not any given system is triple. The variation of the times of eclipses, which has just been described, is a purely geometric effect, depending on the position of the orbit, and it cannot distinguish the two causes of apsidal rotation. Moreover, as will shortly be shown, the presence of a third body will itself produce changes in the times at which the eclipses of the close pair are observed, and these must be allowed for before the presence or absence of apsidal motion may be inferred. Fortunately, the two causes produce differing effects. Apsidal motion changes the times of eclipses because in successive revolutions the eclipses occur when the two stars are in different relative positions in their orbits. When the secondary eclipse is later than predicted, the primary is earlier, and *vice versa*. The two eclipses always vary with exactly opposite phases. The presence of a third body influences the times of minima because the eclipsing pair must move in an orbit about the centre of mass of the three stars. The light from the eclipsing pair must travel different distances at different times. The times of the eclipses themselves are not altered, but only the times at which they are observed. This is the same principle that enabled Roemer to make the first determination of the velocity of light from observations of the eclipses of the satellites of Jupiter. The difference in phase in the variation of the times of the two eclipses, in this case, depends on the change of the distance of the close pair between the two eclipses. The amount of this change varies as the close pair revolves in its orbit, but, provided its period in that orbit is much longer than its eclipsing period, the times of the two eclipses will vary very nearly in phase. In many triple systems the ratio of the two periods is quite large:

in Algol, for instance, it is about 250. On the other hand, in λ Tauri the period of the third body is barely eight times the eclipsing period. The period of apsidal rotation is usually several thousand or even tens of thousands times the orbital period—say anything greater than 25 years. To decide, therefore, whether an observed variation in the times of eclipses is really due to apsidal rotation, it is necessary to observe both eclipses over a long period of time. As a final check, it is desirable to determine the eccentricity of the orbit, upon which will depend the amount of variation in the times of eclipses, produced by apsidal rotation.

The eccentricity, however, cannot always be determined from the light curve alone. In principle it may be, for the displacement of the secondary eclipse depends on $e \cos \omega$, and the difference in the durations of the two eclipses depends on $e \sin \omega$. The latter quantity, however, can seldom be determined accurately, particularly if the secondary eclipse is shallow. For this reason, radial-velocity measurements with the spectroscope can valuably supplement the photometric observations. As the two stars, in a binary, revolve in their orbits, so, of course, their radial velocities change, and a velocity curve, analogous to the light curve, may be constructed from observations of the system (see figure 3). The shape of this curve depends on e and ω, and both of these may be determined from the curve. Often, however, an unexpected difficulty is encountered. When e and ω may be determined from both the light and velocity curves independently, the two sets of values frequently disagree. The best known example of this is U Cephei. The light curve strongly indicates that the orbit is circular, yet the first velocity curve gave $e = 0.47$, $\omega = 25°$. Later ones gave similarly discordant values. Then, in 1950, R. H. Hardie showed that the lines in the spectrum of the star were distorted at certain phases, leading to erroneous velocity measures. It is supposed that a stream of gas between the two stars is superimposing its spectrum on that of the brighter star, whose spectrum alone is normally visible, when the system is viewed from certain angles. Struve and his associates have accumulated much evidence for such streams being the cause of these discrepancies. It is doubtful, however, whether they can be regarded as an universal explanation. Consider, for example, the system of TX Ursae Majoris. This was observed photometrically by, among others, F. B. Wood; and M. Plavec, using all the available times of eclipses found $e = 0.025$ and that the period of apsidal rotation is 34.4 years. The system was also observed spectroscopically at Victoria, for many years, by J. A. Pearce who obtained virtually the same apsidal period namely 35.6 years; he found the eccentricity, however, to be 0.16. It is hardly to be expected that a gas stream will magnify the orbital eccentricity nearly seven times without affecting the apsidal period.

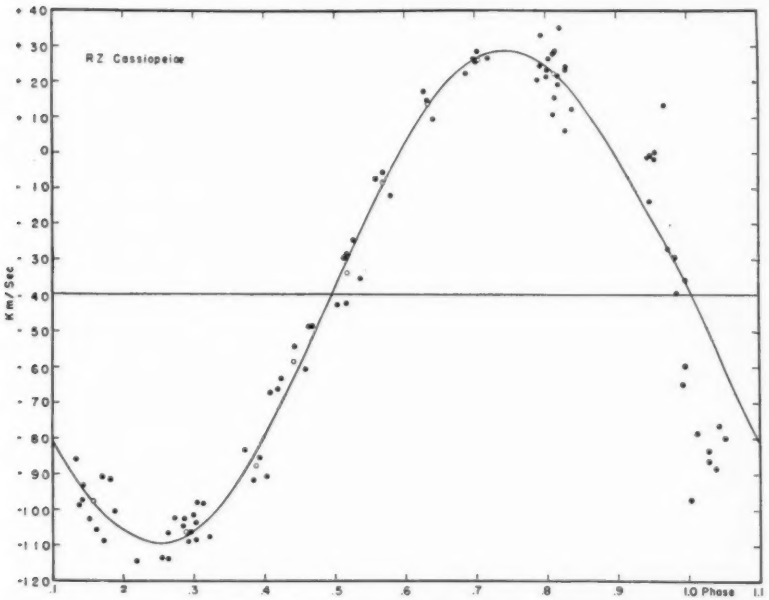


FIG. 3—A velocity curve for the eclipsing system RZ Cassiopeiae obtained by H. G. Horak in 1949–50. The system shows deep partial eclipses, and the rotation effect is conspicuous. It may be seen on the descending branch of the curve; the measured velocities rise steeply from the curve about phase 0.95, and then cross it, to fall below the curve until nearly phase 1.1. The phases are expressed as a fraction of the period. (*Ap. J.*, vol. 115, p. 61, 1952.)

The puzzle is deepened by a later orbit by Hiltner, which has only a small eccentricity. None of the spectroscopic values of ω agree with the photometric values.

Whatever may be the real situation in TX Ursae Majoris, or in any other given binary system, there can be little doubt that many velocity curves are distorted in ways that are not always understood. One kind of distortion which is well understood, however, is that produced by the rotation of a star. One of the first astronomers to study this effect was R. A. Rossiter who observed it in β Lyrae in 1924. It is sometimes called the Rossiter effect but more frequently it is just known as the rotation effect. The sun, of course, rotates, for the sun-spots are carried across its disk, sometimes through several cycles. Probably all stars rotate to a greater or lesser degree, and many rotate very rapidly. Of course, it is not possible to watch "star-spots" crossing stellar disks, so that stars which rotate slowly, like the sun, cannot be caught in the act. A rapidly

rotating star, however, betrays itself by the character of its spectral lines. The light received from a star is made up of light radiated from the whole of its observable hemisphere. If the star is rotating, one limb of its disk is approaching the observer, while the other recedes from him. Thus, the light from one limb shows absorption lines displaced toward the violet, while that from the other shows lines shifted to the red. The total effect in light from the whole disk of the star is one set of broad absorption lines whose width depends on the rate at which the star is rotating. The lines are also shallower, if the star rotates rapidly, because the same absorption is spread over a greater region of the spectrum. As long as the whole of the rotating star remains visible, the measured velocity of the star is its orbital velocity. The broad, shallow absorption lines are difficult to measure, but their centres are not displaced by the rotation of the star, and no systematic errors should be present in the measurement. As soon as part of the star is eclipsed, however, the light is cut off, first from one limb, and then from the other. The observed velocity, therefore, is no longer the orbital velocity, for it includes a contribution from the rotational velocity of the eclipsed star. If the eclipse is total, only a thin crescent of the star is visible for a while just before and after totality, and even a moderate rotational velocity may produce conspicuous departures from the velocity curve (see figure 3). If the eclipse is partial or annular, however, light from one limb is always at least partially balanced by light from near the other, and even a high velocity of rotation will produce a small, but none the less important, effect.

A good example of the difficulties involved in the analysis of these effects is the eclipsing and spectroscopic system of AR Cassiopeiae. This star was first observed spectroscopically in 1906. Since 1933 it has been observed nearly continuously by R. M. Petrie, first at Michigan, but chiefly at Victoria. In 1906 ω was 6°, and it seemed to increase steadily until 1943, suggesting that the line of apsides is rotating with a period of about 400 years. At all epochs the eccentricity is close to 0.25. Until recently the only photometric observations were obtained by Stebbins in 1921. From these he deduced $e = 0.25$, but $\omega = 37°$—at a time when the spectroscopic observations predicted $\omega = 19°$. In the early 1950's the spectroscopic observations lost their consistency, and ω began to vary in a way that cannot be explained on the assumption of two-body motion alone. Meanwhile, a light curve, obtained by Huffer, in 1956, agrees with Stebbins' values for e and ω. This system, therefore, is another example of the discrepancies that arise between photometric and spectroscopic results, although e is given the same value by both methods of investigation.

The system of AR Cassiopeiae is not a very close one, and it is unlikely that there are any substantial gas streams in it. To try to account for the variation in the spectroscopic value of ω, therefore, the present writer introduced, in 1959, the hypothesis of a third member of the system. The evidence for this is the variation in the value of V_0—the velocity of the centre of mass of the binary system. There can be little doubt that this variation is really present. Individual determinations of V_0 have ranged from about -10 km./sec. to -16 km./sec., and the probable error of a single determination is about 1 km./sec. It proved possible to represent this variation quite convincingly with a period of 0.71 years. Many of the orbits already determined were obtained from observations extending over longer intervals than this, and it was hoped to show that if the supposed third-body motion were removed from the observations, the orbits at the various epochs would be made consistent with each other and with the photometric observations. Hypothetical elements of the third body orbit were therefore derived, but not all the discrepancies have been removed, and these elements must be modified. If photometric observations were as plentiful as spectroscopic observations for this system, the presence or absence of both apsidal motion and a third body could be decided from the times of eclipses. Even if both were present, the resulting variation in the eclipse times could be analysed to show they were. Unfortunately, not enough eclipses have been observed to make such an analysis possible: only the velocity curves can reveal these facts.

In the spectrum of AR Cassiopeiae, the lines of only one component are visible. They are very broad lines. The brighter star of the system, therefore, is rotating very rapidly. In fact, in 1955, Slettebak and Howard estimated, from the width of the lines, that a point on the equator of this star has a velocity of at least 160 km./sec. (The corresponding figure for the sun is about 2 km./sec.) It is to be expected, therefore, that there will be some rotational distortion of the velocity curve during eclipses. The effect is small, however, despite the high velocity of rotation, because the eclipses are annular. Nonetheless, calculations showed that the observed velocities should be about 8 km./sec. too high before mid-eclipse, and too low by the same amount afterwards. This could be enough to affect the spectroscopic values of ω, and it seemed worthwhile to find out if the rotation effect is really present in this system. Accordingly, spectrograms were taken during two recent eclipses, on 1960 October 29, when the writer obtained thirteen spectra, and on 1960 November 4, when R. M. Petrie obtained sixteen. These were measured by the writer, and figure 4 shows the differences between the

velocities observed at suitable phases of the eclipse, and the computed orbital velocities. Note the change in the sign of these residuals at mid-eclipse. The lack of symmetry in figure 4 is probably a result of the uncertainty in the value of V_0. The value assumed is -13.9 km./sec.; but -11 km./sec. would suit these observations better. The value of

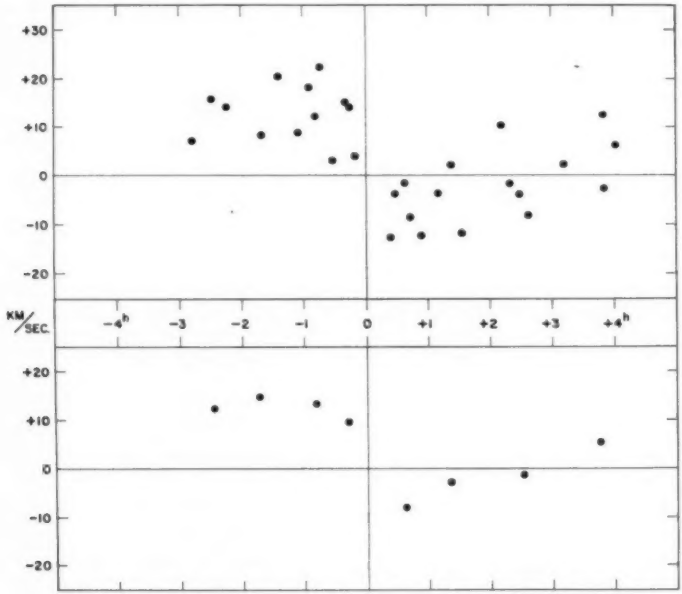


FIG. 4—The upper graph shows the results of individual radial-velocity observations during two eclipses of AR Cassiopeiae. Plotted, are the differences between the observed radial velocities and those computed from the orbital elements. A point falling exactly on the horizontal line has only the orbital velocity. The vertical line is the instant of mid-eclipse. Note how all the points fall above the horizontal line before eclipse, and nearly all of them are below afterwards. The lower graph shows the normal points made up from these observations, from which the rotational velocity was determined.

-13.9 km./sec. is taken from an orbit obtained in 1960 September. With the first value of V_0, the rotational velocity must be at least 200 km./sec., with a mean error of 75 km./sec: the second value, $V_0 = -11$ km./sec., gives a rotational velocity of at least 210 km./sec. ± 50 km./sec. The actual velocity of rotation may be higher, because the position of the axis of rotation is unknown. If the axis makes an angle of 90° with the line of sight, then the measured velocity is the true rotational velocity of the star: otherwise the true velocity is greater. Because the measured

velocity is so high, it is reasonable to suppose that the axis of this star must make an angle close to 90° with the line of sight. The star, however, could rotate with an equatorial velocity of the order of 500 km./sec. before beginning to break up. Many sources of uncertainty exist in the above measures, which are not reflected in the errors quoted. These take account only of the scatter of the normal points used in the determination of the rotational velocity. This is probably the dominant source of error, but the others should be noted. There are the uncertainties in the photometric and spectroscopic elements of the system. The rotating star has been supposed spherical, yet its speed of rotation is high enough to produce considerable flattening at the poles. Finally, and perhaps most important, there is some uncertainty in the degree to which the star is darkened toward the limb. This affects the value of the rotational velocity, because it determines the contribution that the extreme limb makes to the observed velocity. A darkening coefficient of 0.5 was assumed—slightly less than that observed in the sun: this is probably not far from the truth. The agreement with the earlier estimate from the line width is, therefore, satisfactory.

In AR Cassiopeiae, then, there may be present all three of the possible departures from two-body orbital motion which have been discussed in this article: the apsidal motion caused by distorted stars, the perturbations of a third body, and the effect upon the velocity curve, of the rotation of one of the component stars. It may be, on the other hand, that the last of these will be found sufficient to explain those features of the observations which have been found so puzzling. This can only be decided by a lengthy analysis which has yet barely been started. It is hoped, however, that this specific example has given some idea of the complexities of individual cases, in contrast with the simple and general text-book demonstrations of the first part of the article. It is also hoped that the essential unity of spectroscopic and photometric work has been made clear. The distinction between eclipsing and spectroscopic binaries is largely artificial and could profitably be forgotten. It is only by a combined attack on all fronts that full understanding of individual binary systems may be won.

Acknowledgments. The original work described in this article was done during the tenure of a Post-Doctoral Fellowship of the National Research Council of Canada. I wish to express my gratitude to the Council. It is also a pleasure to thank Dr. Petrie for extending to me the hospitality of the Dominion Astrophysical Observatory, and, more especially, for his kindness in helping to obtain the plates here discussed. I am also grateful to Dr. C. M. Huffer for permission to quote results from his unpublished observations.

ROYAL ASTRONOMICAL SOCIETY OF CANADA

MINUTES OF ANNUAL MEETING

The Annual Meeting was held at 8.00 p.m. on Friday, March 17, 1961, in Hart House, University of Toronto, as part of the two-day programme of the Society.

The President, Dr. Peter M. Millman, in welcoming the members and their guests, said that the registration showed that representatives of eleven of the Society's fifteen Centres were present. He said this was evidence of growing contact between the Centres and expressed a hope that this would increase more and more in future years.

A standing roll call revealed that, apart from the large number of Toronto Centre members, there were the following from other Centres: Quebec, 1; Montreal, 10; Montréal, 2; Ottawa, 9; Hamilton, 5; Niagara Falls, 1; London, 1; Windsor, 2; Edmonton, 3; Victoria, 2.

Minutes of the previous annual meeting, held in Toronto on March 11, 1960, were adopted as printed in the JOURNAL (June 1960).

Members stood for a minute's silent tribute to those who had passed on during the last year. The list read by the National Secretary included Dr. Andrew McKellar whose death occurred during his term of office as President; our Honorary President, the Hon. Dr. W. J. Dunlop, and four Honorary Members: Sir Harold Spencer Jones, Dr. Walter Baade, Dr. Samuel A. Mitchell and Dr. F. J. M. Stratton.

The President said that instead of the customary Presidential Address, it had been decided to honour the memory of Dr. McKellar with an address on molecular spectroscopy, a field in which Dr. McKellar had achieved international recognition. He then introduced Dr. A. E. Douglas of the National Research Council who delivered the McKellar Memorial Lecture: "Molecular Spectra in Astronomy and in the Laboratory".

The annual reports for 1960 were then presented in brief. Reporting for the Board of Trustees, Dr. Hossack said the mortgage on the property purchased five years ago had now been paid in full. He thanked the various Centres and individual members who had made donations to the building fund but suggested additional gifts would be welcome. The reports of the National Treasurer, Librarian and National Secretary were adopted as published in the *Supplement* to the JOURNAL which had been distributed to members.

The President announced that the Council had elected two distinguished astronomers to Honorary Membership: Dr. R. van der Riet Woolley and Dr. Alfred H. Joy. Citations on their life and work were read.

The recipient of the Service Award was Mr. Robert Peters of the Victoria Centre, who for more than thirty years has inspired the observing section, and at the age of 89 is still active as director of telescopes. Dr. K. O. Wright accepted the medal on behalf of Mr. Peters.

It was announced that National Council had approved recommendations of the Toronto and Ottawa Centres that the first two awards of the Membership Certificate should be made to Miss Ruth J. Northcott and Miss Miriam S. Burland.

Honorary Life Membership was conferred on Mr. Morris A. Altman who has voluntarily served as the Society's auditor since 1954.

The report of the scrutineers, Mr. James Hogg and the Executive Secretary, Mrs. M. Fidler, was read by the National Secretary. A majority of the 490 ballots returned were in favour of election of the Officers and Council as printed on the ballot. The

ballots returned approved the proposed amendment to Article VII of the Constitution and the amendment to By-Law IV (Life Membership).

The President declared the Officers and Council duly elected and asked the newly-elected officers to stand as they were introduced.

After several announcements concerning the programme to follow on Saturday, the meeting was adjourned and members and guests gathered for refreshments in the Music Room as guests of the Toronto Centre. En route to the Music Room members had an opportunity to view the excellent display arranged by Mr. Vern Ramsay and the Display Committee from material submitted by various Centres.

FREDERIC L. TROYER, *Recorder*

SATURDAY SESSIONS

On Saturday morning, March 18, in the Wallberg Building of the University of Toronto, an audience of over seventy-five heard the following papers read:

The Role of Our Astronomical Society in Today's Neighbourhood, *Franklin C. Loehde*, Edmonton Centre.

Inter-Centre Communication via Amateur Radio, *David Sands*, Montreal Centre.

The Activities of the Centre Français, Montréal, *Fleurange Laforest*, Centre Français de Montréal.

The Role of a Planetarium in the Astronomical Society, *Ian McLennan*, Edmonton Centre.

Venus Observations of the Montreal Centre of the R.A.S.C., *Klaus R. Brasch*, Montreal Centre.

Notes on Auroral Observations in Halifax, *B. W. Allen*, Halifax Centre.

RZ Cassiopeiae—A Fast Changing Variable, *John L. Ruiz*, Dannemora, N.Y.

Meteor Trail Effects on High-Frequency Radio Waves, *Brian Rawlings*, Montreal Centre.

The Bruderheim Meteorite, *Earl R. Milton*, *H. Baadsgaard*, *R. E. Folinsbee* and *L. A. Bayrock*, Edmonton Centre.

Profile of the Fossil Crater at Brent, Ontario, *M. J. S. Innes* and *C. S. Beals*, Ottawa Centre.

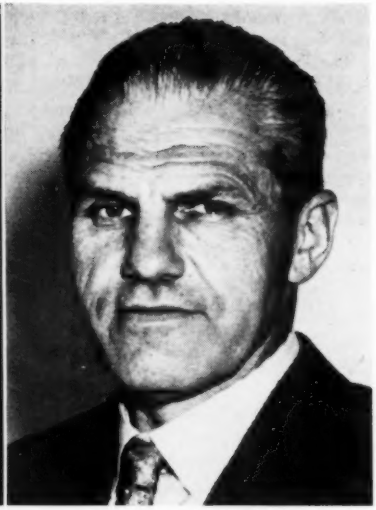
Galactic Nuclei, *Frank P. Morgan*, Montreal Centre.

Two other papers were accepted for delivery at the session.

After lunching in informal groups about seventy members went to Hamilton in two chartered buses to visit the Planetarium at McMaster University. Following the demonstration of the planetarium instrument Professor W. J. McCallion led the group to the Alumni Hall where a very delightful buffet supper was served.

Evening activities were divided among a Council Meeting, a tour of the David Dunlap Observatory and informal meetings and discussions at the National Office.

Dr. A. H. Joy.



Dr. R. v. d. R. Woolley.

ALFRED HARRISON JOY received his Bachelor of Philosophy degree from Greenville College and his Master of Arts from Oberlin College. In 1945 he was awarded an Honorary Doctorate of Science by Greenville College.

He served as Astronomer at Princeton Observatory and at the American University Observatory in Beirut, being Director of the latter institution for six years. After a short period at the Yerkes Observatory, Dr. Joy joined the staff of Mount Wilson Observatory in 1915 and from that date to his retirement in 1952 he made outstanding contributions to astrophysics.

Throughout his astronomical career Dr. Joy's primary interest has been in the spectroscopic analysis of the very luminous stars. In particular he has studied in detail the changes in the spectra of variable stars and has established standards for the determination of absolute luminosities and stellar parallax based on spectroscopic studies.

It is a pleasure to welcome Dr. Joy to Honorary Membership in our Society.

RICHARD VAN DER RIET WOOLLEY received his Master of Science degree at Cape Town and his Master of Arts and Doctorate in Philosophy at Cambridge University, England.

After serving as Chief Assistant at the Royal Greenwich Observatory, and as John Couch Adams Astronomer at Cambridge University, he was appointed Commonwealth Astronomer at Mount Stromlo Observatory and Professor of Astronomy at the University of Canberra, Australia. He was elected a Fellow of the Royal Society, London, in 1953.

In 1956 Dr. Woolley was appointed as Astronomer Royal and Director of the Royal Greenwich Observatory, a position which he holds with distinction at the present time.

Dr. Woolley has carried out research in a number of fields, including a study of the emission spectra of the quiet sun, solar eclipses, monochromatic magnitudes of planets and stars and a study of the stellar populations and the dynamics of star clusters.

The Society is proud to number the Astronomer Royal among its Honorary Members.

SERVICE AWARD

ROBERT PETERS, nominated by the Victoria Centre. Mr. Peters has served the Victoria Centre as Secretary, Vice-President, President and Councillor. In 1930 he helped organize "Summer Evenings with the Stars," still a popular annual feature. For over thirty years Mr. Peters has inspired the Observing Section of the Centre and at the age of eighty-nine is still active as the Director of Telescopes. He is young in heart and deeply esteemed for his unselfish devotion to astronomy and for his genial personality.

AMENDMENTS TO CONSTITUTION AND BY-LAWS

ARTICLE VII: *add the following paragraph*: The National Society does not assume any responsibility for claims arising from actions or omissions of any of the local Centres unless the same have been specifically authorized or undertaken under written instructions from the National Office.

BY-LAW IV: *for the final paragraph substitute*: If a person shall become a Life Member by making the Life Membership payment, and if he wishes to be a member of a Centre, then the whole payment shall be remitted to the National Treasurer and the National Treasurer shall make an annual grant of $1.50 to the Centre during the Life Member's continued membership in the Centre or to such other Centre to which he may be transferred.

NATIONAL OFFICERS AND COUNCIL FOR 1961

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Winnipeg Centre: R. J. LOCKHART, W. W. WRIGHT (President)

(The officers of the Centres are printed in the *Supplement*, p. 18)

NOTES

This report of the Secretary of the Victoria Centre for 1960 was inadvertently omitted from the Supplement—Editor.

REPORT OF THE VICTORIA CENTRE

The regular meetings of the Victoria Centre were held at Victoria College through the kindness of the College authorities. A total of 12 meetings were held in 1960, and the Council met on several occasions to plan the lectures and to discuss the business of the Centre. The speakers and topics at the regular meetings were:

January 13 —J. K. McDonald, Ph.D.: "The Earth's First Satellite".
February 10—H. Richardson, Ph.D.: "The Clock Paradox".
April 13 —Activity Night and Debate, Juniors vs. Seniors: "Going to the Moon".
August 1 —G. J. Odgers, Ph.D.: "The Universe of Stars."
August 8 —K. O. Wright, Ph.D.: "The Earth and its Neighbours".
August 15 —P. E. Bomford: "Numbers, Sizes and Shapes".
August 22 —J. A. L. Muir: "Subjects for Telescopes".
August 29 —Visit to the Dominion Astrophysical Observatory.
October 12 —R. M. Petrie, Ph.D.: "The New 48-inch Telescope of the Dominion Astrophysical Observatory".
November 9—E. K. Lee, M.A.: "Space Astronomy".
December 7—Annual Dinner and Meeting.

The series of five lectures in August made up this year's "Summer Evenings with the Stars". In addition to the regular members, 53 persons registered for this series.

Membership of this Centre for 1960 consisted of 1 Honorary Life Member, 9 Life Members, 23 student members and 71 regular members, making a total of 104 members.

The Centre regrets to report the grave loss through the death of three of its members: Dr. Andrew McKellar, National President; Mr. J. Daniel Francis, Victoria Centre Secretary; and Canon the Reverend C. W. Downer.

AL ANDERSEN, *Secretary*.

METEOR NEWS

By Peter M. Millman

National Research Council, Ottawa, Ontario

The I.G.C. (1959) Visual Meteor Programme—Progress Report No. 5

A summary of the visual meteor observations made during the I.G.Y. on the special meteor programme has appeared in the four previous progress reports. These were published in the Journal, vol. 52, pp. 29, 181, 1958; vol. 53, p. 137, 1959; vol. 54, p. 39, 1960. A grand total of 93,249 meteors was recorded. All this material has now been put on I.B.M. punched cards and is being correlated with the radar meteor counting for the same period.

Visual meteor observations on the same system have been continued since the termination of the I.G.Y. programme on Jan. 31, 1959, and Table I lists all the observations made during the remaining eleven months of 1959. The form of tabulation corresponds to that used in the previous reports. The location of the observing station is followed by the name of the individual who has submitted the observations. It is regretted that there is no room here to print the names of all the observers who took part, but this information will appear later in a bulletin published by the National Research Council. The last four columns list, respectively, the number of different nights on which observations were made, the total number of 10-minute periods covered by the observations, the group total for the meteors observed (each meteor counted only once for each station), and the average number of observers active at one time, including the timekeeper. The I.G.C. (1959) observations contributed a total of 22,634 meteors which, added to the I.G.Y. total, gives us a grand total of 115,883 visual meteors recorded in the two-and-a-half-year period.

The station at Des Plaines, Ill., operated by G. Rippen, once again leads in the number of 10-minute periods observed, followed by Dyer, Ind., and Kanaya #1, Japan. These are all stations manned by a single observer. For the group observations the stations at Ottawa #1, Ont., and Newark #2, Ohio, were the most active. The four divisions of Table I include respectively stations which first contributed in Progress Report No. 1, No. 2, No. 4 and No. 5.

The response to a request for pictures of the various observing groups has been very disappointing. Figure 1 illustrates the observing station Ottawa #1 at the Springhill Meteor Observatory. Eight observing positions are arranged around a timekeeper. Since this is the station

FIG. 1—Part of the visual meteor observation station, Ottawa #1, located at the Springhill Meteor Observatory about 25 miles south of Ottawa.

where the meteor radar is located, all meteors are plotted. Observers are provided with a combination red flashlight, pencil, and push-button which places a marker on the radar film. This combined unit is no larger than an automatic pencil and was developed in the Upper Atmosphere Research Section of the National Research Council. The coffin-like enclosures occupied by the visual observers are supplied with heat from an oil furnace in the small building below.

Sincere thanks go to all those who have worked on this programme and who have thus contributed to its success.

TABLE 1

SUMMARY OF OBSERVATIONS ON THE SPECIAL I.G.C. (1959) VISUAL METEOR PROGRAMME MADE BETWEEN FEBRUARY 1, 1959 and DECEMBER 31, 1959

Location	Name	Nights	Ten-Minute Periods	Meteors Recorded	Average No. of Observers
Baltimore, Md.	K. Delano	28	193	335	1
Bexleyheath, England	K. Herbert	1	19	2	2
Boise, Idaho	J. Westby	1	39	682	11
Brunswick, Ohio	H. Decker	3	20	12	1
Caguas, Puerto Rico	A. Nieves	1	9	13	5
Cape Elizabeth, Me.	R. Dole	21	359	290	1
Cedarhurst, N.Y.	E. Heinhold	3	26	14	1
Cleveland Hts., Ohio	J. Breckinridge	6	31	79	3
Dallas, Texas #2	R. Althauser	12	286	1524	6
Des Plaines, Ill.	G. Rippen	166	1667	2465	1
Dyer, Ind.	J. Berg	61	692	3969	1
Edmonton, Alta. #2	E. Milton	7	57	561	5
Elyria, Ohio	G. Diedrich	3	31	84	5
Fort Wayne, Ind. #2	D. Nelson	2	21	12	1
Hamilton, Ont.	J. C. Craig	5	67	137	6
Islip Terrace, N.Y.	W. Webster	14	60	104	1
Kingston, Jamaica	E. C. Melville	5	30	42	4
Lodi, Calif. #1	R. Birch	4	28	56	1
Lucerne, Switzerland #1	E. Roth	15	152	569	3
Montreal, P.Q.	E. E. Bridgen	22	252	696	5
Moose Jaw, Sask.	E. Freidin	9	69	268	6
New York, N.Y. #4	A. Pearlmutter	25	235	1523	3
Omaha, Neb.	C. Moroson	10	102	239	2
Ottawa, Ont. #1	Miss M. S. Burland	25	524	1533	9
Pittsburgh, Pa.	W. A. Feibelman	56	471	407	1
Poughkeepsie, N.Y.	F. Greer	3	18	10	1
Regina, Sask. #1	M. Madjen	1	12	121	1
San Jose, Calif.	S. Bieda	3	37	251	5
Vancouver, B.C. #1	M. Taylor	3	18	145	4
Arlington, Calif.	H. E. Kaiser	18	236	209	7
Beacon Falls, Conn.	T. J. Bohuski	28	450	811	1
Houston, Texas #1	D. Milon	9	136	1051	5
Kanaya, Japan #1	K. Komaki	85	686	903	1
Kibi, Japan	Mrs. F. Iwasaki	29	216	330	1
Leavenworth, Wash.	S. Emig	2	45	509	2
Red Bluff, Calif.	F. Wyburn	37	451	484	1
Salem, Ohio	V. Taus	2	16	39	3
Sheffield, Ala.	R. May	19	131	115	1
Vancouver, B.C. #2	J. B. Wilson	3	6	21	2
Wellington, New Zealand	N. K. Keen	1	7	11	1

Location	Name	Nights	Ten-Minute Periods	Meteors Recorded	Average No. of Observers
Newark, Ohio #2	N. R. Colangelo	45	512	72	2
Sacramento Peak, N.M.	G. Schwartz	1	24	98	1
Schenectady, N.Y.	J. Keane	16	104	62	1
Seymour, Conn.	H. Kushpinsky	4	95	206	1
Weyburn, Sask.	K. Baker	2	30	250	6
Winnipeg, Man. #1	J. Scatliff	3	22	72	2
Kanaya, Japan #3	Y. Hata	45	365	332	1
Northfield, Minn.	R. Althauser	1	14	101	9
Cambridge, Mass.	S. Maran	1	15	50	1
Camp Borden, Ont.	E. Madjen	2	24	38	2
Cooksville, Ont.	J. Kennedy	6	48	173	2
Eau Claire, Wis.	G. Rippen	1	43	65	1
Fergus Falls, Minn.	D. Nelson	2	19	138	1
Harrison, Mich.	Z. Abrams	1	7	9	1
Montgomery Centre, Vt.	Miss I. Williamson	1	24	207	19
Munro, Jamaica	E. E. Bridgen	6	8	7	1
Richfield, Minn.	B. Warren	1	11	7	1
St. John's, Nfld.	R. Joyce	2	12	25	1
Siren, Wis.	G. Rippen	8	75	86	1
Winnipeg, Man. #4	R. D. Bendall	1	1	1	1
Winnipeg, Man. #5	J. Stewart	1	5	9	1
	TOTAL		9,363	22,634	

NOTES FROM OBSERVATORIES

DOMINION OBSERVATORY, OTTAWA, ONT.

Positional Astronomy: A new precision quartz oscillator now controls the carrier frequencies and signal pips which emanate from C.H.U., the Dominion Observatory transmitters. Since January the oscillator has been maintained within about one part in 10^9 by daily reference to the caesium atomic standard at the National Research Council. The Photographic Zenith Telescope in its new location is completely automatic, with devices to close the roof in case of precipitation or bright sky. Sub zero weather caused some failures which have not yet been entirely eliminated. In spite of these failures, more P.Z.T. observations were obtained last November and December than in the corresponding months of any previous year. On February 11, photographic observations of Echo I (1960i) were attempted.

Stellar Physics: The 84-foot radio telescope at Penticton began regular observations last November. The first programme involves a study of the distribution of neutral hydrogen in associations of early-type stars. The automatic guider for the horizontal solar telescope has been completed and initial tests are being performed. The Hα solar flare patrol has been put in operation again to help bridge the longitude gap between Europe and the western United States. Several additional holes were drilled in the Brent crater in Algonquin Park to give a good picture of the crater contour before the sediments were deposited.

Gravity: Last October and November, the drilling of three holes in the Brent crater was supervised. Preliminary examination of cores from these holes has confirmed predictions concerning the depth of the crater based on analysis of gravity measurements. In co-operation with the Topographical Survey, detailed investigations of the crater in Ungava known as the New Quebec or Chubb crater and of the circular features at Clearwater Lake were made in March. Measurements of gravity were made on the ice, water depths were measured, and samples from the bottom were obtained for subsequent analysis.

Seismology: The seismic network in Canada is being extended so that eventually no point in Canada will be more than 300 miles from a first-class seismograph station. All stations, including the existing ones, will be equipped with identical instruments of the most modern type. A good beginning has been made on this programme. Stations at Halifax,

Ottawa, Resolute, Penticton and Victoria have been brought up to the new standard, plans for new stations at Alert, Mould Gay, Schefferville and Fort St. James are well advanced, and sites have been selected and surveyed for several other stations.

Personnel: Recent visitors to the Observatory have included Dr. K. O. Wright of the D.A.O., but currently at the David Dunlap Observatory, Dr. H. S. Hogg of the David Dunlap Observatory and Dr. J. Scatliff, President of the Winnipeg Centre, R.A.S.C. Dr. C. S. Beals was honoured by Queen's University when the degree of LL.D. was conferred on him at their fall Convocation. Dr. Beals, Miss M. S. Burland and Messrs. M. M. Thomson and R. W. Tanner attended meetings of the National Committee for Canada, I.A.U., in Kingston last November. Mr. Thomson was the speaker at one of the symposia held at that time. Dr. I. Halliday attended the Christmas meetings of the American Astronomical Society held in New York. Dr. E. R. Niblett represented the Observatory at a Symposium in Boston, on the Intense Magnetic Storm of November 12–16, 1960. Mr. J. M. Grant of the Meanook Meteor Observatory returned to Ottawa in December to assist with meteor reductions, for an interval of several months. The following staff members are assisting with a series of lectures at Carleton University on "Physics of the Earth"—Drs. Innes, Hodgson, Whitham, Niblett, Kollar and J. G. Tanner. The series has been arranged this year by Dr. E. R. Niblett of the division of Geomagnetism, Sessional Lecturer at Carleton University. Dr. I. Halliday and Messrs. M. M. Thomson and R. W. Tanner attended the Annual meeting of the R.A.S.C. in Toronto in March.

MIRIAM S. BURLAND

REVIEW OF PUBLICATIONS

Astronomischer Jahresbericht edited by K. Heinemann, F. Henn, W. Lohmann. Volume 58, The Literature of the Year 1958. Astronomischen Rechen-Institut in Heidelberg. Pages xviii + 567; $5\frac{7}{8}\times8\frac{7}{8}$ in. (paper). Berlin, Walter de Gruyter & Co., 1960. Price 60 DM.

Once again this invaluable volume has appeared, representing the co-operative effort of more than 40 European astronomers, working predominantly, but not exclusively, in Germany. Their summaries of the flood of astronomical literature occupy 531 pages of abstracts. In itself, the printed list of journals summarized forms a convenient list of astronomical literature, and the list of observatories and institutions is a guide to those which are currently contributing to astronomical research. The 27 pages of author's names (pages 533–559) form an excellent roster of astronomers who are contributing to the astronomical literature. In vol. 48 of the *Jahresbericht* for 1948, this name index occupied only 13 pages. This indicates not only the enormous growth in the number of astronomers in recent years but also the ever-increasing labour of the editors and contributors of the *Jahresbericht* to make available to astronomers in concise form the great mass of astronomical papers today. Another sign of the times is that the section on astronautics and rockets (which includes earth satellites) now occupies 30 pages. When it first appeared in vol. 47 for 1947 it occupied one page.

HELEN SAWYER HOGG

Der Sternenhimmel 1961 edited by Robert A. Naef. Pages 142; $5\frac{3}{4}\times8\frac{1}{4}$ in. (paper). Aarau, Switzerland, H. R. Sauerlander and Co., 1960 (North America: Albert J. Phiebig, Box 352, White Plains, New York).

This is the yearbook of the Swiss Astronomical Society and is written in German. It contains much the same kind of information as is printed in our *Observer's Handbook*, but has some additional features. For example, there are drawings of some of the planets, and tables giving the positions of certain features on Jupiter and Saturn. It is an excellent compendium of astronomical information.

RUTH J. NORTHCOTT

Beyond the Planet Earth by Konstantin Tsiolkovsky trans. by Kenneth Syers. Pages 190; $5\frac{1}{4}\times8$ in. New York, Pergamon Press Inc., 1960. Price $3.75.

Tsiolkovsky's genius is clearly displayed in this interesting fantasy. Tsiolkovsky was a self-taught, self-reliant and independent thinker with a vaulting imagination, and it was inevitable that he would have difficulty in making his arguments for space travel seem convincing to his contemporaries. A plausible story embodying these arguments was an obvious means of making them appear feasible, and this, no doubt, is why the tale was written.

First published in 1920, the book embodies predictions for space travel which are astonishingly up-to-date. The narrative begins in the year 2017 at a scientific retreat high in the Himalayas. There, an international team of scientific geniuses with unlimited resources successfully embarks on the conquest of space. The main interest lies in the application of scientific logic to the great adventure, and not to any melodramatic interplay of personalities. The story is rather naïve from a literary standpoint, although the translation reads well. The consistently valiant optimism imposes on credibility. The almost unbroken succession of triumphs in the acquisition of techniques not even yet fully in sight, must have made readers forty years ago skeptical, to say the least. For example, the author assumes thrust and endurance capabilities in his rockets which, we can now say, indicate prescience of nuclear power.

The book should be of interest to both lay and scientific readers. There are many facts and figures in the story, but a minimum of jargon. It is a historical landmark, and should kindle imaginations for years ahead.

Tsiolkovsky's epitaph, written by himself, provides the book's theme:

"Man will not always stay on earth; the pursuit of light and space will lead him to penetrate the bounds of the atmosphere, timidly at first, but in the end to conquer the whole of solar space."

M. G. Whillans

VARIABLE STAR NOTES

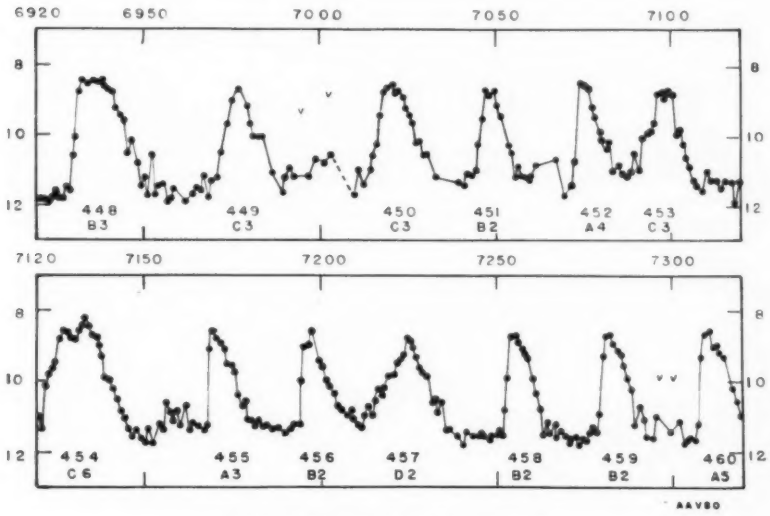
By Margaret W. Mayall

The American Association of Variable Star Observers, Cambridge, Mass.

NOTES ON U GEMINORUM-TYPE VARIABLES

213843 *SS Cygni*. The most famous and best observed of the U Geminorum-type variables, SS Cygni, had one of the most active years in its recorded history, in 1960. Twelve maxima were observed, nearly double the normal activity. Fortunately, observations were made during the period when Cygnus passes from the evening sky to the morning sky, and no maxima were missed.

Observations were made on 319 nights during the year. A total of 1,529 observations was received from 64 observers. This total included 310 observations by 11 members of the Scandinavian *Astronomisk Selskab*, sent to us by the director, Axel V. Nielsen; and 71 observations from 3 members of the Variable Star Section of the Swedish Astronomical Society, sent by the director, Gunnar Darsenius. Mr. Darsenius deserves congratulations for his fine work in setting up the Variable Star Section. Report No. 1, containing times of observed maxima of 4 long-period variables, a small flare of AD Leonis, observed on May 3, 1960 by Eric L. Alexandersson, and 1,670 observations of irregular variables made by 8 members of the Section has just been published as part of the Gothenburg University Astronomical Notes No. 4.



Mean light curve of SS Cygni, 1960

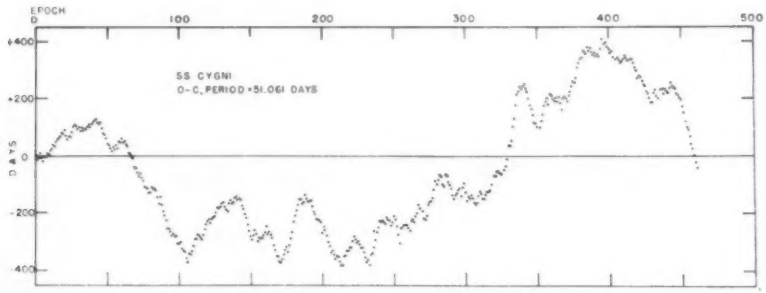
The mean light curve of SS Cygni (plotted from daily means) and the table of data of the observed maxima are continuations of those published annually in these Variable Star Notes. The maxima are numbered consecutively from the discovery in 1896. The first column of the table gives the number of the maximum; the second column the type of maximum according to Leon Campbell's classification; the third, fifth and seventh columns give the Julian Day when the variable is at the 10th magnitude on the increasing branch of the curve, when it is at maximum, and when it has decreased to 10th magnitude, respectively; the fourth, sixth and eighth are differences; and the ninth column gives the mean maximum magnitude.

1960 MAXIMA OF SS CYGNI

Max. No.	Type	10.0 I J.D.	Diff.	Max. J.D.	Diff.	10.0 D J.D.	Diff.	Max. Mag.
448	B3	2436931	49	2436936	49	2436945	53	8.4
449	C3	6973	42	6977	41	6982	37	8.7
450	C3	7017	44	7020	43	7027	45	8.6
451	B2	7045	28	7048	28	7053	26	8.7
452	A4	7073	28	7074	26	7080	27	8.5
453	C3	7093	20	7098	24	7102	22	8.7
454	C6	7123	30	7132	34	7140	38	8.4
455	A3	7168	45	7169	37	7176	36	8.6
456	B2	7194	26	7197	28	7202	26	8.6
457	D2	7219	25	7224	27	7231	29	8.8
458	B2	7253	34	7255	31	7261	30	8.7
459	B2	7280	27	7282	27	7288	27	8.7

The sparsity of A-type maxima is noticeable during 1960. The mean frequency of types is as follows: A, 61%; B, 12%; C, 19%; D, 8%. In 1960 the frequencies are: A, 17%; B, 42%; C, 33%; and D, 8%.

The mean interval between the 12 maxima of SS Cygni during 1960 is 33 days. The mean for all maxima since its discovery is 51.1 days. An $O-C$ (observed minus computed) curve was computed for the 460 observed maxima of SS Cygni, assuming the mean interval to be a period of 51.061 days. The resulting curve is plotted in the accompanying diagram. A plot of the intervals between maxima shows a slight tendency to a cyclical trend, which also shows up in the $O-C$ curve.



Errata. In the list of maxima of SS Cygni for 1959 (this JOURNAL, vol. 54, page 150), an error was made in listing the dates for number 445. For Max. J.D. read 6808, for Diff. read 49, for 10.0D J.D. read 6818, for Diff. read 52. In line for Max. No. 446, for Diff. 40 read 50; for Diff. 34, read 44.

020356 *UV Persei*. A 12.5 magnitude maximum was observed on *7228*, 346 days after the last maximum.

060547 *SS Aurigae*. Four maxima observed, on *6972*, 11; *7038*, 10.8; *7211*, 11; and *7274*, 11.

061115 *CZ Orionis*. The following maxima were observed; *6939*, 12.2; *6986*, 11.8; *7013*, 12.4; *7259*, 12.1; and *7282*, 12.0.

074922 *U Geminorum*. No maxima were missed during 1960, and four were observed as follows: No. 374, wide, *7016*, 9.2; No. 375, narrow, *7082*, 10.1; No. 376, wide, *7177*, 9.1; and No. 377, narrow, *7255*, 9.9.

080362 *SU Ursae Majoris*. About 10 maxima were observed during the year. The star should be observed with telescopes reaching the 14th magnitude, as maxima are seldom brighter than 11.5 and minimum is about 14.5.

094512 *X Leonis*. Maxima were observed as follows: *6994*, 12.0; *7013*, 12.4; *7048*, 12.0; and *7068*, 12.2. Several other possible maxima depend on single observations.

184137 *AY Lyrae*. The following maxima were observed: *7014*, 12.8; *7111*, 13.5; *7128*, 13.4; *7144*, 13.0; *7178*, 12.9; *7215*, 12.4; and *7260*, 13.6. All maxima were narrow, with the exception of those at *7014* and *7215*.

184826 *CY Lyrae*. Five maxima were observed: *7144*, 12.8; *7167*, 13.3; *7185*, 13.4; *7200*, 13.4; and *7229*, 13.2.

195109 *UU Aquilae*. Two maxima were observed as follows: *7030*, 11.5; and *7200*, 11.3.

203501 *AE Aquarii*. The usual rapid variations were noted during the year.

220912 *RU Pegasi*. Four maxima were observed during 1960, as follows: *6942*, 10.9; *7052*, 10.8; *7180*, 10.7; and *7276*, 10.6.

A.A.V.S.O. Nova Search Report (from George Diedrich, Chairman). Observations of nova search areas were made by the following 15 observers for a total of 286 area-nights reported. Each name is followed by the number of observations made in November and then December 1960.—Mrs. E. E. Bridgen—14, 6; F. J. DeKinder—18, 18; D. Diedrich—5, 7; G. Diedrich—9, 12; K. Fuller—12, 0; G. Gaherty, Jr.—2, 0; W. Isherwood, Jr.—38, 36; J. Low—2, 10; D. W. Orchiston—21, 12; R. Price—0, 1; F. Traynor—10, 8; W. A. Warren—0, 8; K. A. Wells—6, 12; I. K. Williamson—9, 3; and K. Zorgo—6, 0.

In addition, the following reports have not been reported previously: October K. Fuller—29; June and July—J. Low—6, 3; October—D. W. Orchiston—8; August—G. W. Smith—8.

Observations received during January and February 1961: A total of 7,354 was received: 4,011 from 63 observers in January, and 3,343 from 77 observers in February.

Observer	January		February		Observer	January		February	
	Var.	Ests.	Var.	Ests.		Var.	Ests.	Var.	Ests.
Adams, R. M.	100	171	89	151	Lucas, D.	...	...	6	10
Ahnert, P.	12	259	...	...	McDonagh, E.	...	...	4	23
Anderson, Carl	6	9	...	...	McPherson, C. A.	23	23	17	17
Anderson, Curtis	6	6	63	111	Mende, R.	...	...	10	49
*Axelson, K.	14	31	14	14	Miller, R. W.	...	...	26	26
Ayala R., H.	4	12	3	20	Miller, W. A.	7	7	13	14
Barroso, J. J.	...	...	8	8	Montague, A. C.	20	25	30	38
Bartha, L.	...	...	2	2	Morgan, F. P.	20	27	22	22
Bicknell, R. H.	5	17	...	...	Morrow, E. O.	7	8	...	...
Brady, R. F.	22	22	33	85	Mourilhe S., P.	6	6	10	22
Braune, W.	...	...	26	95	Murphy, A. T.	9	12	3	3
Bream, G.	5	5	4	4	Newton, C. S.	1	1	2	2
Buckstaff, R. N.	17	29	12	24	Oberstatter, A.	...	...	8	12
†Burt, S.	34	315	16	163	Olmsted, M.	11	11	5	5
Conklin, R.	...	...	9	16	Oravec, E. G.	197	347	...	...
Cragg, T.	234	314	252	278	Orchiston, D. W.	...	...	33	165
Darsenius, G.	...	...	5	5	Peltier, L. C.	28	141	21	81
de Kock, R. P.	111	469	141	448	Petik, P.	1	1	...	...
Diedrich, DeL.	1	1	...	...	Quester, W.	...	...	10	17
Diedrich, G.	4	4	2	2	Renner, C. J.	...	...	46	50
Engelkemeir, D.	12	31	12	24	Rizzo, P. V.	6	6	5	7
Erpenstein, O. M.	10	10	4	4	Robinson, L. J.	124	161	53	59
Fernald, C. F.	87	100	72	89	Rosebrugh, D. W.	17	70	15	73
Ford, C. B.	11	13	7	7	Schiff, S.	14	16	6	7
Frogel, J. A.	3	3	3	4	Sealy, R. N.	...	...	4	4
Gardner, B. E.	4	13	3	21	Seavey, H. O.	8	25	8	13
Giffen, C. H.	1	1	...	...	Sharpless, A. P.	26	28	34	35
Glenn, F. R.	5	7	...	...	Sherwood, D. A.	8	13	8	16
Glenn, W. H.	5	10	...	...	‡Shinkfield, R. C.	...	...	10	30
Gonthier, A.	4	4	5	6	Smith, J. R.	...	...	11	11
Halbach, E. A.	...	...	6	6	Specht, H. E. M.	2	11	...	...
Hampton, W. R.	2	2	...	...	Szekely, C.	5	21	4	17
Hartmann, F.	146	156	127	137	Taboada, D.	314	638	159	339
Hicks, R. L.	5	15	6	29	Thomas, M. A.	1	2	...	...
Hiett, L.	6	11	...	...	Thompson, J. R.	...	...	1	1
Honda, H.	48	115	44	90	Tompkins, R.	...	...	2	2
Hurless, C.	6	35	3	12	Travis, N.	2	9	2	4
Judd, D.	7	7	18	18	Traynor, F. N.	...	...	7	10
Kaminski, W. J.	...	...	7	10	Tsai, C. H.	...	...	17	20
Kelly, F. J.	10	15	11	31	van Zyl, L. L.	43	88	37	72
Knowles, J. H.	8	13	8	10	Vodrazka, G.	...	...	6	6
Lacchini, G. B.	18	33	18	29	Ward, D.	...	...	1	5
Lehmann, P. B.	...	...	20	65	Williamson, L. J. A.	...	...	4	5
Lewindon, F.	...	...	2	3	Williamson, P. L.	...	...	1	1
Loblay, R.	...	...	4	6	Worcester, B.	1	2	...	...
Lorenz, E. O.	12	15	11	12	Yamada, T.	27	39	11	11

*83^m UV Cet; 71^m YZ CMi
†34^m 0² Eri: 125^m Ross 42; 93^m AD Leo
‡1^h 11^m UV Cet

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Vol. 55, No. 3 **JUNE 1961** **Whole No. 450**

Molecular Spectra in Astronomy and in the Laboratory ..... *A. E. Douglas* 101

The Removal of a Chromium Base Layer From an Optical Mirror *John F. Heard* 112

Wilhelm Heinrich Walter Baade, 1893–1960 ..... *Halton C. Arp* 113

Sir Harold Spencer Jones, 1890–1960 ..... *W. M. Smart* 117

CANADIAN SCIENTISTS REPORT–XXVI

Stellar Eclipses and Stellar Interiors ..... *Alan H. Batten* 120

ANNUAL MEETING OF THE R.A.S.C.

Minutes of Meeting 132

Report of the Session for Papers 133

New Honorary Members 134

Service Award 135

Amendments to Constitution and By-Laws 135

National Officers and Council for 1961 135

NOTES 136

METEOR NEWS ..... *Peter M. Millman* 137

NOTES FROM OBSERVATORIES ..... *Miriam S. Burland* 141

REVIEW OF PUBLICATIONS

Astronomischer Jahresbericht edited by K. Heinemann, F. Henn, W. Lohmann; *Der Sternenhimmel 1961* edited by Robert A. Naef; *Beyond the Planet Earth* by Konstantin Tsiolkovsky, trans. by Kenneth Syers 143

VARIABLE STAR NOTES ..... *Margaret W. Mayall* 145

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